Groundwater Phytoremediation System-Performance at the SRSNE Superfund Site

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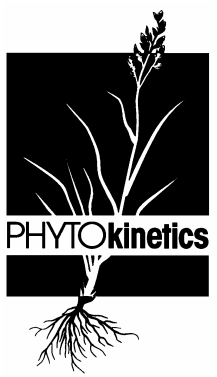


Outline of Presentation

- Solvents Recovery Service of New England (SRSNE) Superfund Site in Southington Connecticut
- Groundwater phytoremediation project
  - Objective
  - Preliminary greenhouse project
  - Installation and stand development
- Monitoring
- Phytoremediation system-performance
- Costs
  - Costs for phytoremediation project
  - Projected cost savings for client

SRSNE Superfund Site

- Former solvents recovery/recycling facility
- Groundwater contaminants:
  - Volatile organic compounds, including chlorinated solvents, aromatics, ketones and alcohols
  - DNAPL plus dissolved-phase groundwater plume
- Existing conventional remediation system
  - Barrier wall
  - Containment area
  - Groundwater recovery system
  - Water treatment facility

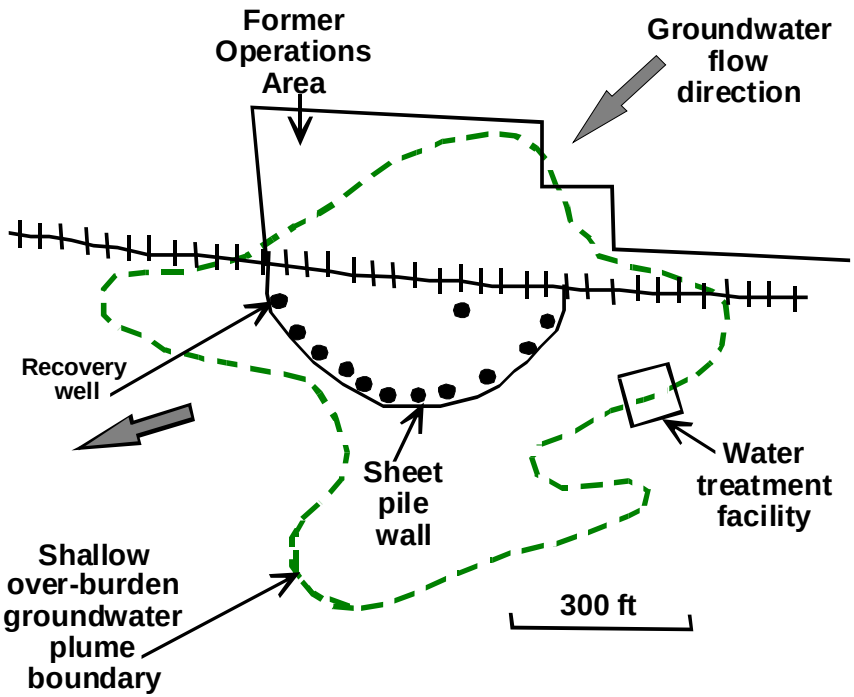
SRSNE Superfund Site

Aerial photo, 1980

- SRSNE reclaimed spent industrial solvents for re-use, 1955 to 1991
- Source areas include former lagoons, drum and tank areas, and processing area
- EPA declared the SRSNE a Superfund site in 1983

Existing Conventional Remediation System:

Non-time critical removal action (NTCRA) system has controlled the migration of the most highly contaminated groundwater since 1995



- Sheet pile wall driven to bedrock
  - *700-ft long*
  - *30-ft deep*
- Twelve groundwater recovery wells pump 19 gpm year-round
- UV-oxidation water-treatment facility removes ~850 kg VOCs per year
- Compliance criterion: *Inward hydraulic gradient toward the containment area*

Sheet-pile wall, groundwater recovery well, and the water treatment facility

Groundwater Phytoremediation Project

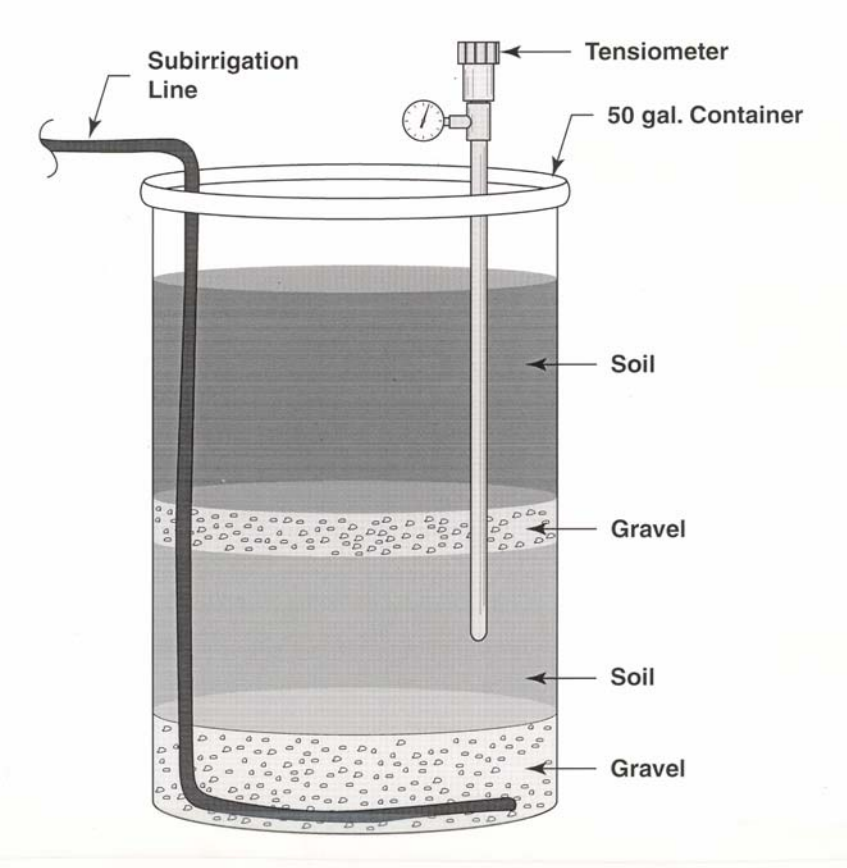
Containment area at SRSNE site
(Depth-to-groundwater: 4 to 5-ft bgs)

- Stand of trees (0.8 acre) was established in the 1.2 acre containment area
- Objective:
  - "Pump and treat" contaminated groundwater
  - ***Reduce the need for mechanical pumping and treatment, at least on a seasonal basis***
- Processes:
  - "*Pumping*": water use by the tree stand
  - "*Treatment*": removal of mass of VOCs by various phytoremediation processes

Preliminary Greenhouse Experiment

- Objective: To evaluate the potential toxicity to poplar trees of the dissolved groundwater contaminants at the SRSNE site
- Experimental:
  - The toxicity of a VOCs cocktail in poplar trees was determined
  - VOCs cocktail: Mimicked the groundwater at the SRSNE site: *Chlorinated alkanes, alkenes, aromatics, ketones, alcohols*
- Treatments:
  - Control (*water only*)
  - Three different concentrations of VOCs cocktail *(45 to 170 mg/L)*

Preliminary Greenhouse Experiment (*continued*)



- Poplar saplings were sub-irrigated with VOCs cocktail
- Phytotoxicity evaluated by measuring various physiological parameters:
  - *Stomatal conductance*
  - *Shoot elongation*
  - *Biomass production*
  - *Leaf area*
  - *Root growth*

Preliminary Greenhouse Experiment (*continued*)

- Result: No significant change in the physiological parameters at any dose of VOCs
- Results suggested that a full-scale installation at the SRSNE site was feasible
- *International Journal of Phytoremediation*
  Vol 1, pp 9-17, 1999.

Phytoremediation System at the SRSNE Site: *Chronology*

- Initial planting, 1998
  - 1000 hybrid poplars (*P. deltoides x nigra*)
  - late May
  - 60% survival
- Re-planting, 1999
  - 400 white willow (*S. alba*)
  - early April
  - >95% survival
- Hybrid poplar trees removed
  - May 2002
  - Canker infestation (*Cryptodiaporthe populea*)
- Phytoremediation system at SRSNE site in Summer 2004:
  372 willow trees on 0.8 acre

Planting Methods (1998) *(Initial)*

- Trenches were dug in the Containment Area

  (4 to 5-ft deep)

- Hybrid poplar cuttings were deeply planted in backfilled trenches

Planting Methods (1999) (*Re-Planting*)

- Boreholes were drilled in the backfilled trenches from the previous year
- White willow cuttings were deeply planted in the backfilled boreholes

Stand Development

Summer 1998

Summer 1999

Stand Development (*continued*)

Summer 2000

Summer 2001

Stand Development (*continued*)

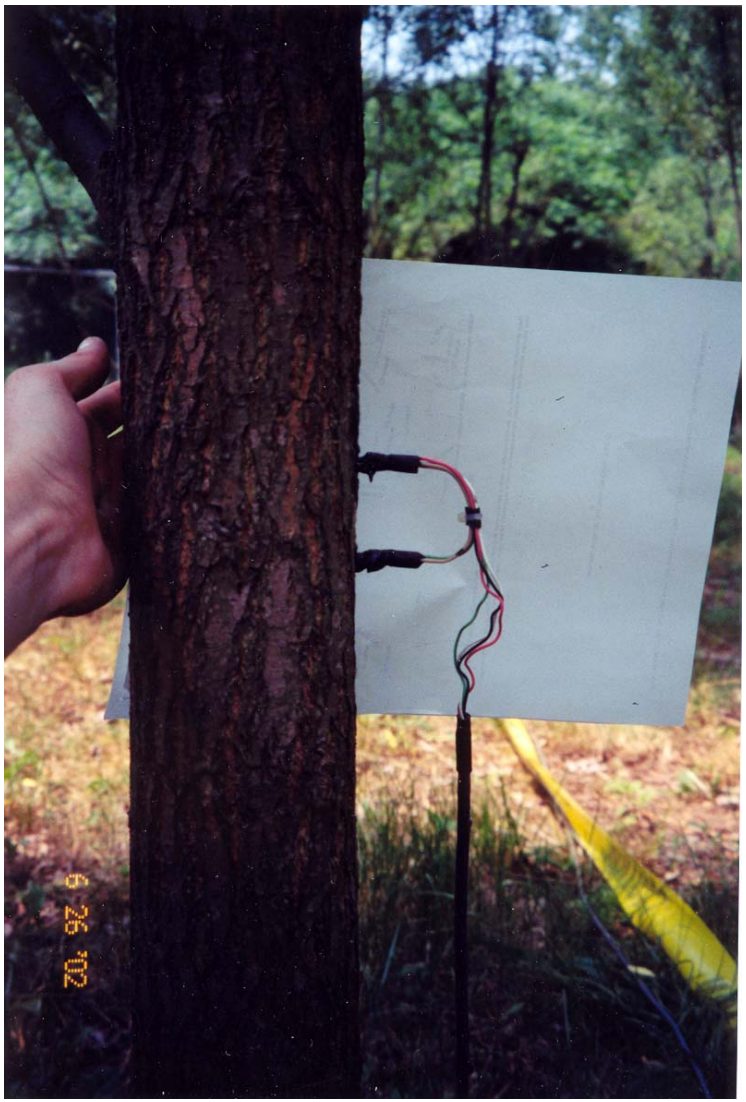
Summer 2002
(pure willow stand)

Summer 2003

Stand Development (*continued*)

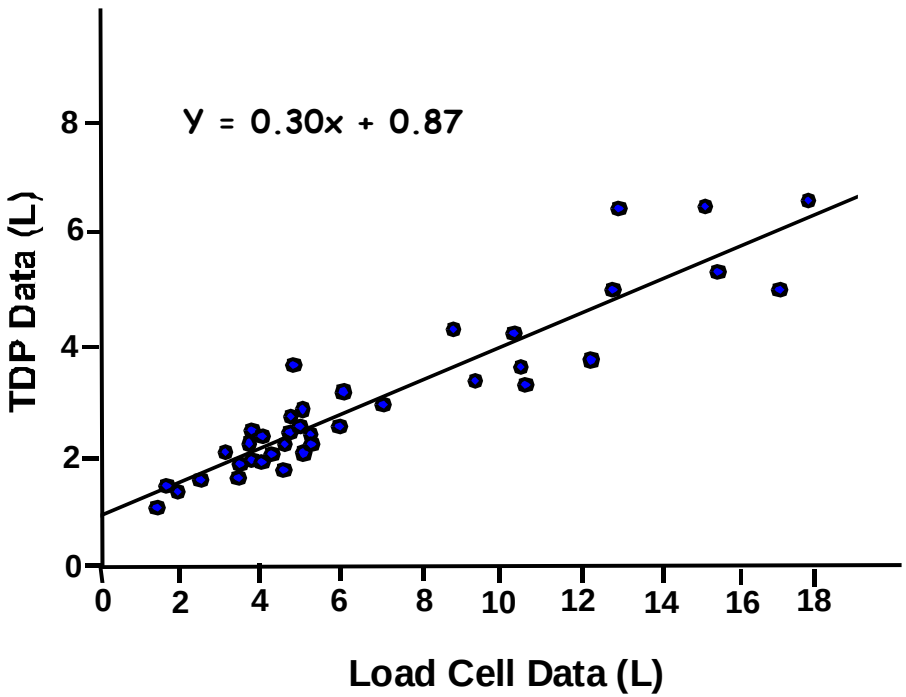
Summer 2004

Monitoring Methods



- Thermal dissipation probes (TDPs) were used to measure sap velocity
  - Two needle-like sensors are inserted into holes drilled in the xylem
  - Upper needle is heated, and the temperature difference between the two needles (ΔT) is measured
  - When sap velocity is high, heat in the upper needle is dissipated, and ΔT is reduced
- Values for ΔT and sap velocity are imperically related (Granier, 1985)
- The product of sap velocity (cm/h) and cross sectional area of the stem (cm^2) yields sap flow (cm^3/h)

Monitoring Methods (*Continued*)



- Calibration study compared TDP data with load-cell data
  - Professor Roger Kjelgren *Dept. Plant Science, Utah State Univ., Logan, Utah*
  - *Populus nigra* were grown in 20 gal containers. Each of the three containerized trees was placed on a load-cell.
  - Four TDPs per tree, 12 TDPs total
  - Actual water use was determined from the change in container weight
- Result: Granier's empirical relationship underestimated sap velocity by approximately 45% (*Int. J. Phytoremed*. 3, 87-104, 2001).

Phytoremediation system at SRSNE site

Monitoring Results

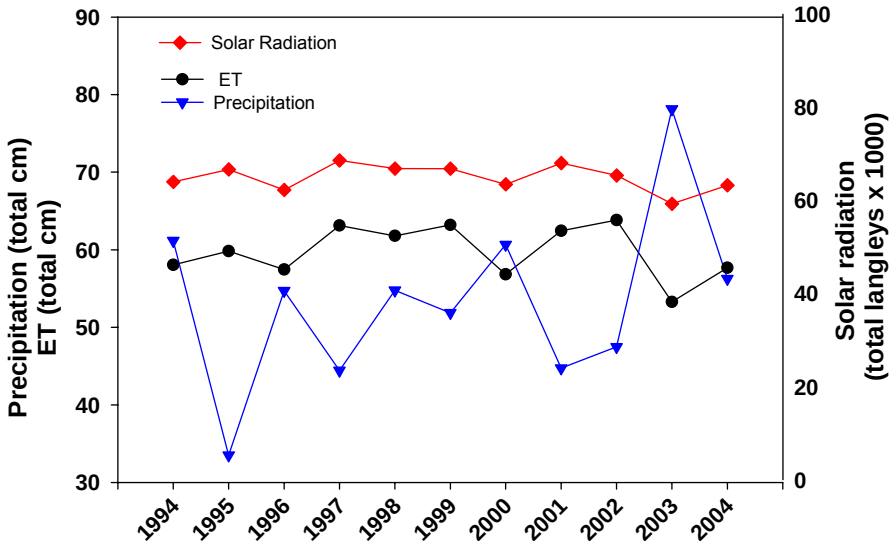
TDP data for instrumented willow trees analyzed *using Kjelgren's calibration factor.* Data are mean summertime values (May through September).

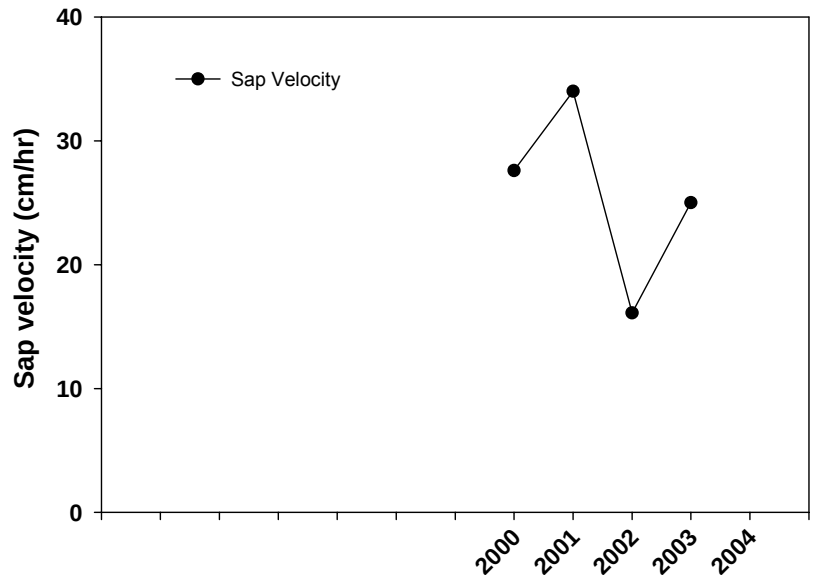
Year	n	Sap velocity (cm/h)	Basal area (cm^2)	Sap flow (L/d)
2000	5	27.8	40.8	27.2
2001	5	34.7	35.4	29.5
2002	7	16.5	67.1	26.6
2003	7	27.6	108.5	71.9
Edwards (1986)* (*Salix matsudana*)		51.3	86.0 (*sapwood*)	106.0

*W.R.N. Edwards, 1986, Precision weighing lysimetry for trees, using a simplified tared-balance design. *Tree Physiol*. 1, 127-144. *The study was done in Palmerston North, New Zealand (growing season ET_o = 56.5 cm*). [Southington Connecticut, growing season ET_o = 59.7 cm]

Monitoring Results

Comparison of mean sap velocity data and weather station parameters for May through September (*weather station data are totals for the season*)





Scaling the TDP Data to the stand-level

Mean values for May through September for the 0.8 acre stand of willow trees planted in 1999

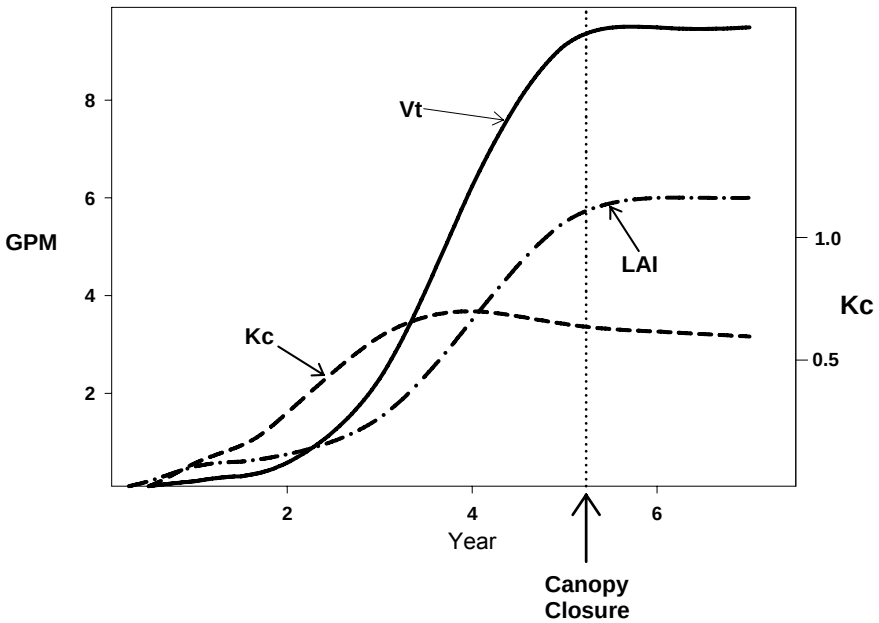
Year	Sap velocity (cm/h)	Basal area (m^2)	Stand water use (gpm)
2000	27.8	n/a	--
2001	34.7	1.4	2.1
2002	16.5	3.0	2.2
2003	27.6	3.7	4.5
2004	*26.7**	6.8	8.0

*mean value for sap velocity, 2000 to 2003

Phytoremediation of Organic Solvents in Groundwater: Pilot Study at a Superfund Site

Ari Ferro and Brandon Chard (Phytokinetics, Inc., Logan, Utah), Michael Gefell (Blasland, Bouck, and Lee, Inc., Syracuse, New York), Bruce Thompson (de maximis, inc., Simsbury, Connecticut, Roger Kjelgren (Utah State University, Logan, Utah).

In: Bioremediation and Phytoremediation of Chlorinated and Recalcitrant Compounds. G.G. Wickramanayake, A.R. Gavaskar, B.C. Alleman, and V.S. Magar (eds.), pp. 461-466. 2000. Batelle Press, Columbus, OH

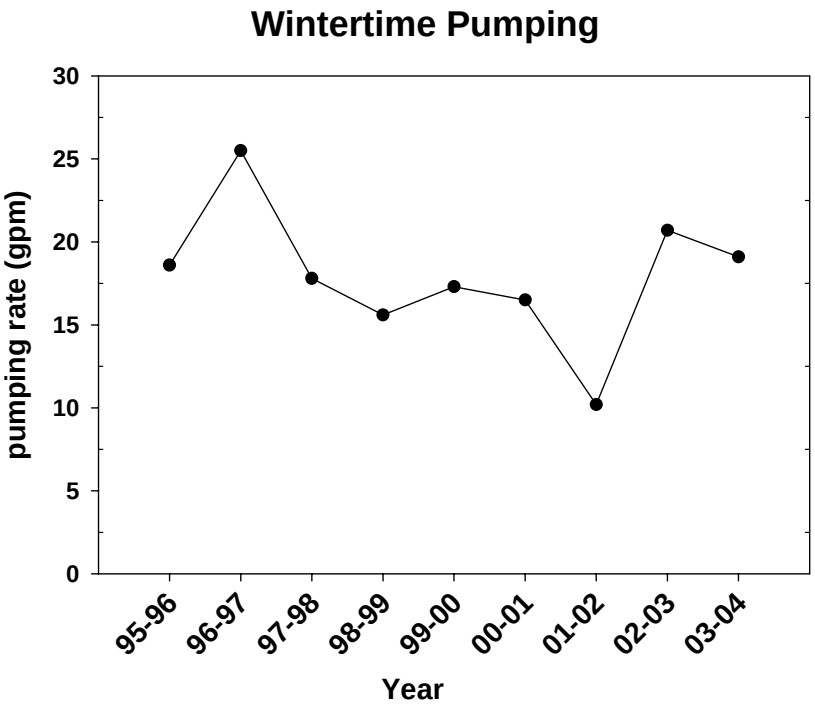


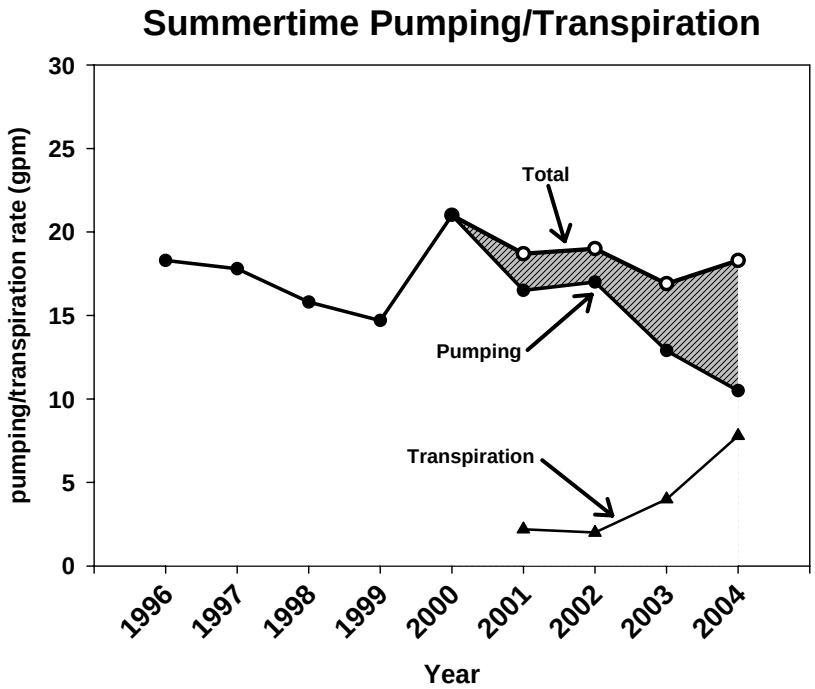
Rate of water use for the stand was estimated:

- Vt = PET*Kc* LAI*A
- A = 0.8 acres
- Original assumption:
  950 poplar trees
- Current System:
  372 willow trees planted in 1999 (2004 was sixth growing season)

System Performance

Objective of the phytoremediation system: Reduce the need for mechanical pumping and treatment, at least on a seasonal basis





Cost of the Phytoremediation System

Item	Cost
Proposals/Presentations/Work Plans	$15,500.00
Greenhouse studies	$40,400.00
Installation (1998)	$115,300.00
Replanting (1999)	$40,700.00
Maintenance and Monitoring (2000-2003)	$70,700.00
Total Cost	$282,600.00

Projected Cost Savings for Client*

Year	Stand water use		Cumulative Cost Savings (millions)	Net Cost Savings (millions)
	gpm	gal/season (millions)		
2001	2.1	0.47	$ 0.02	- $ 0.26
2002	2.2	0.47	$ 0.05	- $ 0.23
2003	4.5	0.95	$ 0.09	- $ 0.19
2004	8.0	1.7	$ 0.18	- $ 0.10
2005	9.0	1.9	$ 0.27	- $ 0.01
2006	9.0	1.9	$ 0.37	+ $ 0.09
2007	9.0	1.9	$ 0.46	+ $ 0.18
2008	9.0	1.9	$ 0.56	+ $ 0.27
2009	9.0	1.9	$ 0.65	+ $ 0.37
2010	9.0	1.9	$ 0.75	+ $ 0.47

*Assumptions:

- Cost for conventional groundwater treatment = $0.05/gal
- Mean summertime stand transpiration rate will plateau in 2005 at 9 gpm
- Total cost of phytoremediation system = $282,600
- The trees in the phytoremediation system will be allowed to stand until autumn 2010

Conclusion
Groundwater Phytoremediation System-Performance at the SRSNE Site

- The phytoremediation stand is now a self-sustaining natural system
- There will be no further significant project costs
- Net cost savings for the client
  - *Break-even point will occur in 2005*
  - *By 2010, the phytoremediation system will have saved $470,000 in groundwater treatment expenses*

PHYTOkinetics

de maximis, inc.